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**6. AUTHOR(S)**
Mark A. Grosenbaugh, Richard P. Trask, & Robert A. Weller

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

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The objectives of this project have been to: (develop a systematic design procedure for severe-environment moorings which will include dynamic analysis to predict the lifetiem of the mooring components; (2) use dynamic and fatigue analysis to preform parametric design studies of cnadidate moorings for severe environments; (3) apply the design principles and specifications developed in this study to the design of the Arabian Sea moorings.

This surface mooring design will provide a platform which time series of high quality near-surface meteorology, air-sea fluxes of momentum, heat and freshwater, and upper ocean variability can be obtained in the Arabian Sea. In addition, areas once thought to be too severe for surface mooring deployments can be reconsidered as potential sites for making moored measurements similar to those being made in the Arabian Sea.

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18 December 1994

**Mark A. Grosenbaugh, Richard P. Trask, and Robert A. Weller**

# Arabian Sea Surface Mooring

**Woods Hole Oceanographic Institution**
**Woods Hole, Massachusetts 02543**
**mgrosenbaugh@whoi.edu, rtrask@whoi.edu, rweller@whoi.edu**
**phone: (508)457-2000 ext 2607 (MAG), 2395 (RPT), 2508 (RAW)**
**fax: (508) 457-2165**

**Long Term Goals:**

The Arabian Sea is strongly forced by the monsoons winds. Field studies of the processes that contribute to the physical and biological variability observed near the surface in the Arabian Sea began in October 1994. Surface moorings are a critical component of the field studies, providing the ability to measure the air–sea fluxes and the upper ocean variability. Our long term goal is to work toward having the capability to design surface moorings that can be used in high wind and large wave conditions.

**Objectives:**

The objectives of this project have been to: (1) develop a systematic design procedure for severe-environment moorings which will include dynamic analysis to predict the lifetime of the mooring components; (2) use dynamic and fatigue analysis to perform parametric design studies of candidate moorings for severe environments; (3) apply the design principles and specifications developed in this study to the design of the Arabian Sea moorings.

**Approach:**

To begin the design process the environmental conditions (i.e., ocean current and wave data and wind data) expected in the Arabian Sea were researched. Maximum instrument oading on the mooring was then determined based on static and dynamic analyses of the mooring.

Dynamic analysis performed on candidate moorings involved calculating ynamic tensions as a function of the natural frequency of the mooring and the istrument load. Discrete mooring components were then cyclically loaded in a laboratory setting to the tensions predicted by the dynamic analysis. The fatigue life determined from these tests was used to select the proper mooring component (i.e., shackles, links, wire rope, chain, and instrument cages) sizes. The results of these tests were then used to refine the mooring design.

**Tasks Completed:**

A literature search has been conducted to identify the environmental conditions that can be expected in the Arabian Sea. Available ocean current profile data was

compiled for used with the static design analysis. Wind and wave data were also collected and are being used in conjunction with the dynamic analysis.

Several different mooring configurations have been analyzed using the ocean current information compiled for the area. These candidate designs were evaluated on the basis of instrument performance and static and dynamic loading.

Fatigue tests have been conducted on several sizes and types of shackles, weldless sling links, weldless end links, wire rope, chain, and instrument cages using several load ranges. Design changes to the candidate mooring were made based on the safe-life fatigue analysis. Mooring components that were found to be susceptible to a fatigue failure were either redesigned, or replaced with a stronger part. If a suitable part could not be found then as a last resort the mooring payload was reduced.

The results of the dynamic analysis for each sea state are in terms of the standard deviation and the average frequency of the tension. The standard deviation was used to predict the probability distribution for the peak tension, and the average frequency was used to predict how often a peak is likely to occur.

This information was combined with the environmental data and the fatigue test data to predict the life expectancy of the mooring components. The environmental data gave the probability for each sea state. The dynamic analysis gave the distribution of the peak loading for each sea state. Combining these data, we calculated the distribution of peak loading for the duration of the deployment. The fatigue-test data was used with the peak distribution to calculate component life expectancy. Components with life expectancies several times greater than what was actually required were chosen to compensate for uncertainties in the actual environmental conditions that will be encountered and unknown affects of corrosion on fatigue life.

A final mooring design was agreed upon, and the mooring was fabricated. In October 1994 the mooring was successfully deployed.

**Results:**

The fatigue tests identified several mooring components susceptible to failure under the conditions expected in the Arabian Sea. Instrument cage failures during the tests prompted new fabrication specifications as well as a redesign of the instrument end bales. Test results indicated that the pear-shaped weldless sling link should be replaced by a more oval component called a weldless end link. The pear ring is more susceptible to flexing and therefore crack propagation than the oval shaped link. The weldless end links were used throughout the Arabian Sea mooring. The fatigue life of shackles was found to be greatly enhanced by the process of shot peening. Shot peening is a process whereby a component is blasted with small spherical shot which in turn produces a surface layer with a residual compressive stress zone. Since cracks

do not tend to initiate or propagate in a compressive stress zone the fatigue life of the part is increased. This process improved the fatigue life of the shackle without having to physically increase its size.

**Impact:**

This surface mooring design will provide a platform from which time series of high quality near-surface meteorology, air–sea fluxes of momentum, heat and freshwater, and upper ocean variability can be obtained in the Arabian Sea. In addition, areas once thought to be too severe for surface mooring deployments can be reconsidered as potential sites for making moored measurements similar to those being made in the Arabian Sea.

**Transitions:**

We are presently seeking contacts in any of the Navy Labs who might have an interest in the results of the hardware fatigue tests. The results of this work will benefit others involved in the design of and specification of the hardware used in surface moorings and other dynamic applications.

**Relationship to Other Projects:**

The Arabian Sea surface mooring supports instrumentation from five principal investigators. The field work is done in close collaboration with the other physical and biological oceanographic components of the ONR Arabian Sea program and with the JGOFS Arabian Sea field program.

**Publications:**

Dickey, T. D., D. V. Manov, R. A. Weller and D. A. Siegel, 1994. Determination of longwave heat flux at the air–sea interface using measurements from buoy platforms. *Journal of Atmospheric and Oceanic Technology*, **11**(4), 1057-1078.

Weller, R. A., D. L. Rudnick, and N. J. Brink, 1994. Meteorological variability and air–sea fluxes at a closely spaced array of surface moorings. *Journal of Geophysical Research*, in review.

Weller, R. A., and A. J. Plueddemann, 1994. Observations of the mean vertical structure of the oceanic boundary layer. *Journal of Geophysical Research*, in review.

Plueddemann, A. J., J. A. Smith, D. M. Farmer, R. A. Weller, W. R. Crawford, R. Pinkel, S. Vagle, and A. Gnanadesikan, 1994. Oceanic observations of Langmuir circulation: From drifters to Doppler. *Journal of Geophysical Research*, in review.

Hosom, D. S., R. A. Weller, R. E. Payne and K. E. Prada, 1994. The IMET (Improved METeorology) ship and buoy systems. *Journal of Atmospheric and Oceanic Technology*, accepted.

Plueddemann, A. J., R. A. Weller, M. Stramska, T. Dickey, and J. Marra, 1994. The vertical structure of the upper ocean during the Marine Light–Mixed Layer experiment. *Journal of Geophysical Research*, submitted.

Stramska, M., T. Dickey, J. Marra, A. Plueddemann, C. Langdon, and R. Weller, 1994. Bio-optical variability associated with phytoplankton dynamics in the North Atlantic Ocean during spring and summer of 1991. *Journal of Geophysical Research*, accepted.

Rieder, K. F., J. A. Smith, and R. A. Weller, 1994. The influence of wave direction on the open ocean wind stress vector. *Journal of Geophysical Research*, accepted.

Dickey, T., J. Marra, M. Stramska, C. Langdon, T. Granata, R. Weller, A. Plueddemann, and J. Yoder, 1994. Bio-optical and physical variability in the Sub-Arctic North Atlantic Ocean during the spring of 1989. *Journal of Geophysical Research*, in press.

Grosenbaugh, M. A., 1994. Designing oceanographic moorings to withstand fatigue. *Journal of Atmospheric and Oceanic Technology*, submitted.

Trask, Richard P. and Nancy J. Brink, 1993. The Subduction Experiment, cruise report, R/V *Oceanus* cruise number 240, leg 3, Subduction 1 mooring eployment cruise 17 June–5 July 1991. *Woods Hole Oceanographic Institution Technical Report*, WHOI-93-12, 77 pp.

Trask, Richard P. and Nancy J. Brink, Lloyd Regier and Neil McPhee, 1993. The subduction experiment, cruise report, R/V *Oceanus* cruise number 250. *Woods Hole Oceanographic Institution Technical Report*, WHOI-93-13, 102 pp.

Trask, Richard P., William Jenkins, Jeffrey Sherman, Neil McPhee, William Ostrom and Richard Payne, 1993. The subduction experiment, cruise report, RRS *Charles Darwin* cruise number 73. *Woods Hole Oceanographic Institution Technical Report*, WHOI 93-18, 402 pp.

Trask, R. P., N. Galbraith, P. Robbins, W. M. Ostrom, L. Regier, G. Pezzoli, and N. McPhee, 1993. The Subduction Experiment, Cruise Report, R/V *Knorr* Cruise number 138, leg XV, Subduction 3 Mooring Recovery Cruise, *Woods Hole Oceanographic Institution Technical Report*, WHOI-93-54, 83 pp.

**Presentations (Weller):**

Langmuir Circulation, COFTEL seminar, May 20, WHOI.

Air–Sea Fluxes during TOGA COARE, The Oceanography Society meeting, invited talk, June 21.

Moored observations of the surface meteorology and air–sea fluxes in the western equatorial Pacific during the TOGA Coupled Ocean Atmosphere Response Experiment, June 21–22, poster with Steve Anderson.

Moored observations of the variability and structure of temperature, salinity, and velocity near the surface of the western equatorial Pacific warm water pool during the TOGA Coupled Ocean Atmosphere Experiment, June 21–22, poster with Steve Anderson.

**Graduate Students (Weller):**
Anand Gnanadesikan, graduated September 1994.

**Service (Weller):**

Editor, Contributions in Oceanography, U.S. National Report, 1991–1994, American Geophysical Union.
Associate Editor, *Journal of Atmospheric and Oceanic Technology.*
Member, Committee on Radio Frequencies, National Research Council.
Member, Panel on Near-Term Development of the Operational Ocean Observations, National Academy of Sciences/National Research Council.
Member, Global Energy and Water Cycle Experiment (Panel), National Academy of Sciences/National Research Council.
Chairman, Science Steering Committee for Long-term Ocean Observations (LTOO) component of NOAA Climate and Global Change Program.
Member, JSC/CCCO Ocean Observations System Development Panel (OOSDP).
W.O.C.E. (World Ocean Circulation Experiment) International Indian Ocean Special Studies working group.
TOGA Coupled Ocean Atmosphere Response Experiment (COARE) Science Working Group.
Co-Chairman, TOGA COARE Working Group on Air–Sea Fluxes.
American Geophysical Union, Translations Board (term ends December 1994) and Macelwane Medal Committee.